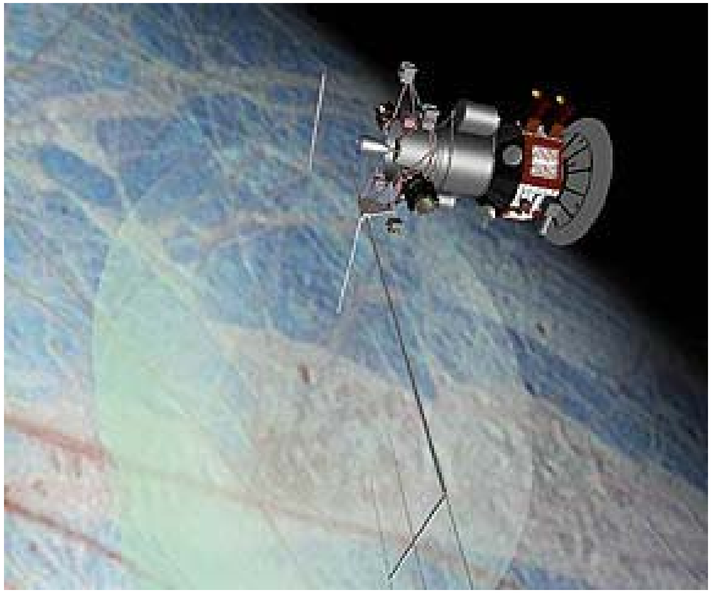
Concept briefing to NASA Headquarters
October 2, 2001

"Exobiological Exploration of Europa (E^3) - Europa Lander"



Frederic Stillwagen
NASA Langley Research Center
f.h.stillwagen@larc.nasa.gov

Ram Manvi / Chuck Weisbin
Jet Propulsion Laboratory
rmanvi@jpl.nasa.gov
Charles.R.Weisbin@jpl.nasa.gov

Europa Lander Mission Overview

Place a Lander on the surface of Europa

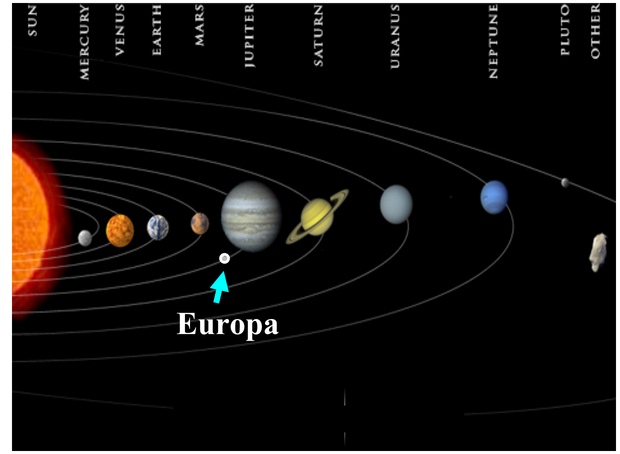
Survivability: Mrads & >-140^{o}C

Drill and navigate through the frozen surface (Cryobot)

Swim and navigate the liquid 'oceans' (Hydrobot)

Search for evidence of 'LIFE'

Report findings

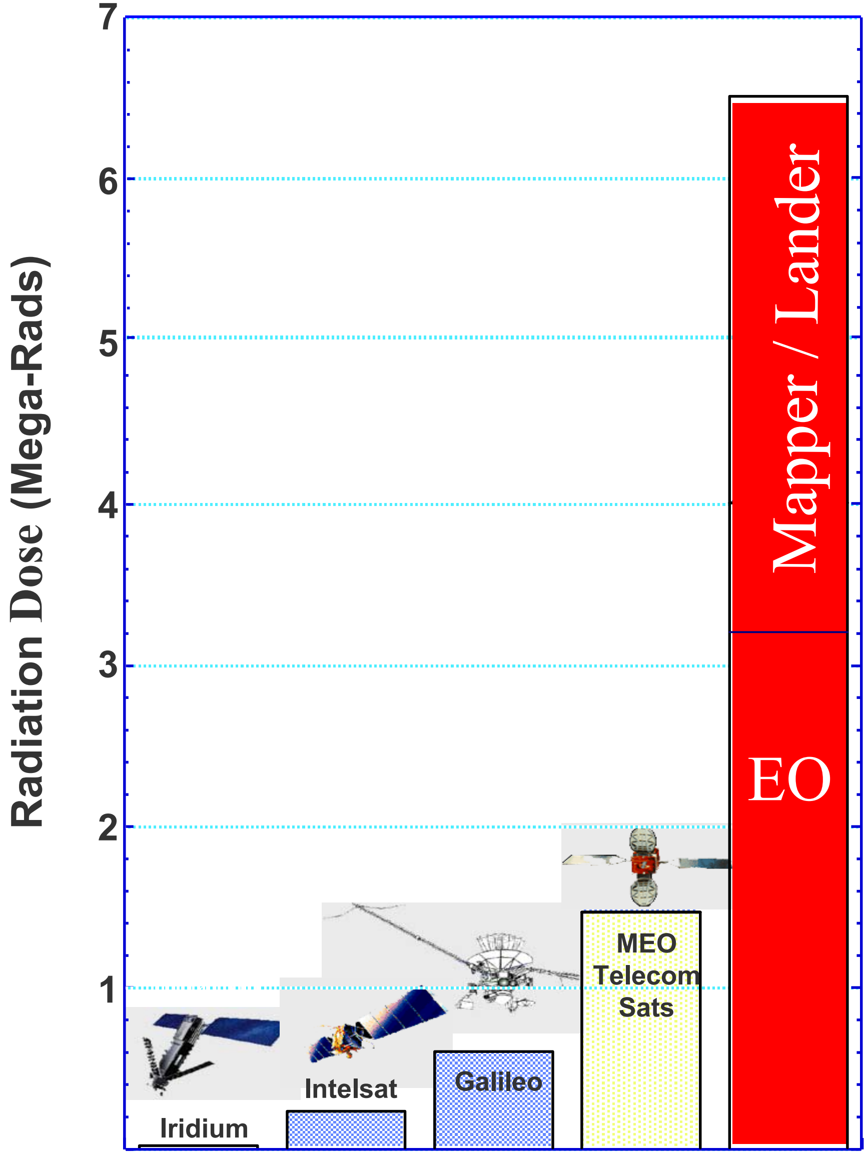


Europa, fourth largest satellite of Jupiter, has gained the rank of one of the highest priority targets for an outer Solar System exploration mission. If liquid water were to exist on Europa, it would not be unrea-sonable to speculate on the existence of life there, perhaps forming near undersea volcanic vents.

Europa Lander Specifications (& goals)

- Survival: ~2 Years
  - Surface Lander (2); Cryobot (2); Submersible (1)
- Provide capability to penetrate up to 3 Km of frozen surface
- Lander Dry Mass: 560 to 800 kg (to include Mapping instruments)
  - On Surface Facility: ~325 to 450 kg
  - Cryobot: ~ 110 to 150 kg
  - Submarine:~ 125 to 200 kg
- Power: Submarine: 50 to 120 W;
  - Cryobot: ~ 1kWt; 20 to 65 W
- Descent & Landing with precision guidance capability for enhanced performance; hazard avoidance capability for increased reliability
- Communications between Lander, Cryobot and Hydrobot at various rates
- Avionics redundancy, and hot backup for increased reliability
- Direct-to-Earth semaphores and communications (commands, telemetry & video/images) ; communications support with a Relay Orbiter
- Rad Hard Electronics for Lander on the Europa Surface: >1 Mrad Survivability during 2 Years

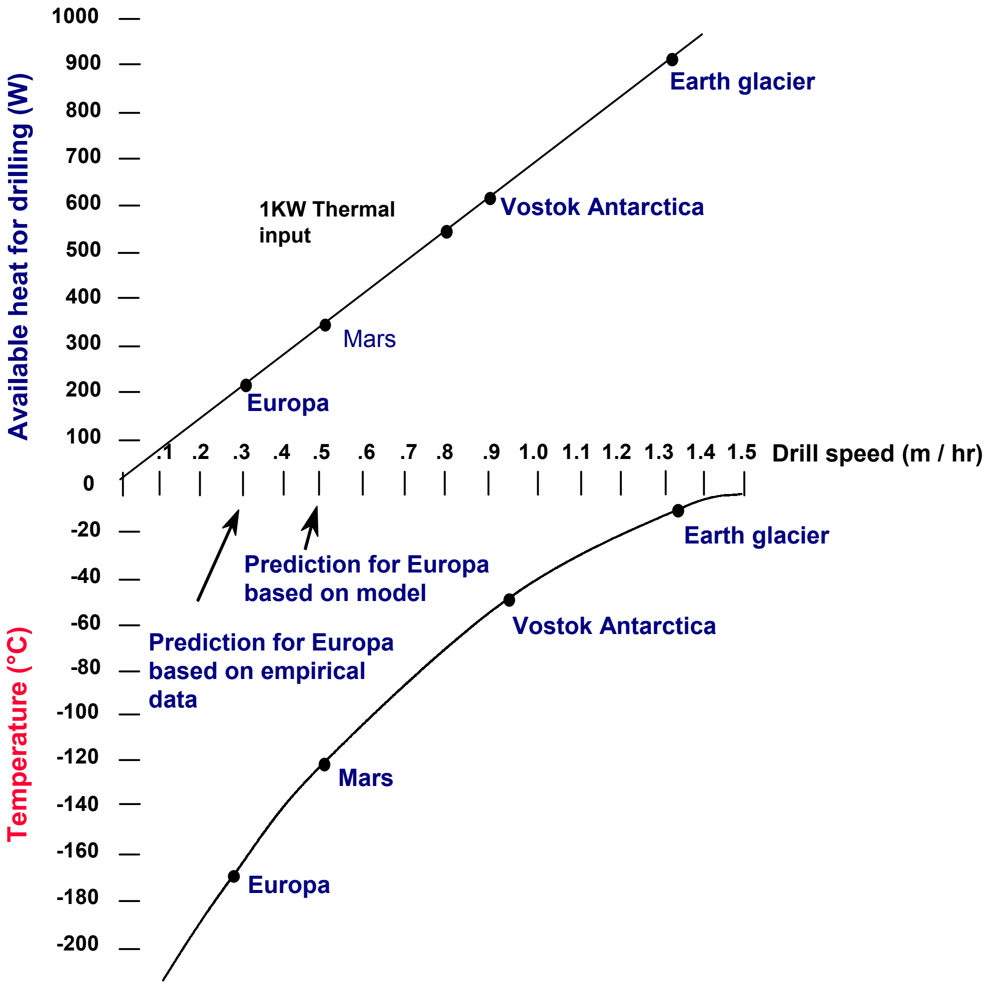
Europa Lander Mission Characteristics



Technical Challenges

- Radiation Environment: The Europa Mapper/Lander total dose environment while in orbit (~1-2 months) is harsh compared to current experience
- Radiation Environment: The Relay total dose environment is dependent on Jupiter orbit characteristics and 2+ year lifetime
- The Europa Mapper/Lander must survive & operate with high reliability during the 2-year mission in extreme radiation → several (Mrads)

Europa Lander Mission Characteristics



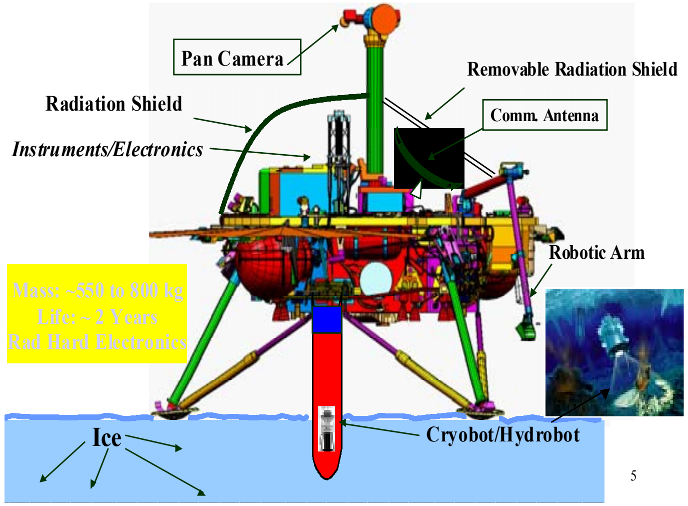
Technical Challenges

- The Europa Lander must survive & operate with high reliability during the 2-year mission in extreme thermal environments (> -140^{O}C).
- Cryobot/Hydrobot must achieve Substantial ice penetration (~3-5 km)
- Cryobot/Hydrobot must be robust, intelligent, mass & power efficient for complete autonomy. Survivability for ~1 year
  - Melt Control
  - Stability & Control
  - Autonomous Descent
  - Intelligent Decision Making
  - Thermal Control & Related Fluid Mechanics
- Through-the-ice data transmission of science data and camera pictures; transfer data to Earth
- Science platform & electronics miniaturization and life detection; mass reduction

Europa Lander: Trade Space

- **Propulsion:**
  Advanced Liquid, SEP, NEP, NTP
- **Europa Landing:**
  Direct, Pump-Down, Autonomous Hazard Avoidance, Precision Landing
- **Survivability:**
  Rad Hardened, Shielding, Thermal Control
- **Power:**
  Nuclear Sources (Small Reactor, Radio-Isotopes), ARPS, Stirling Engine
- **Surface Penetration:**
  Drills, Cryo-bot, structures
- **Communications:**
  Tethered, RF, X/Ka-band, Optical
- **Hydro-bot Mobility:**
  Tethered Submersible, Submarine
- **Life Detection:**
  Mass Spectrometers, SEM, DSC, CEP

Europa Lander Concept

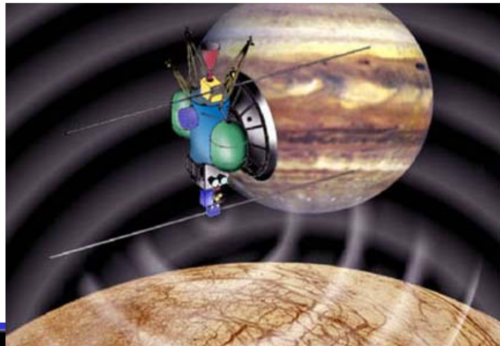


•Compile Cost & Performance information and document the sources

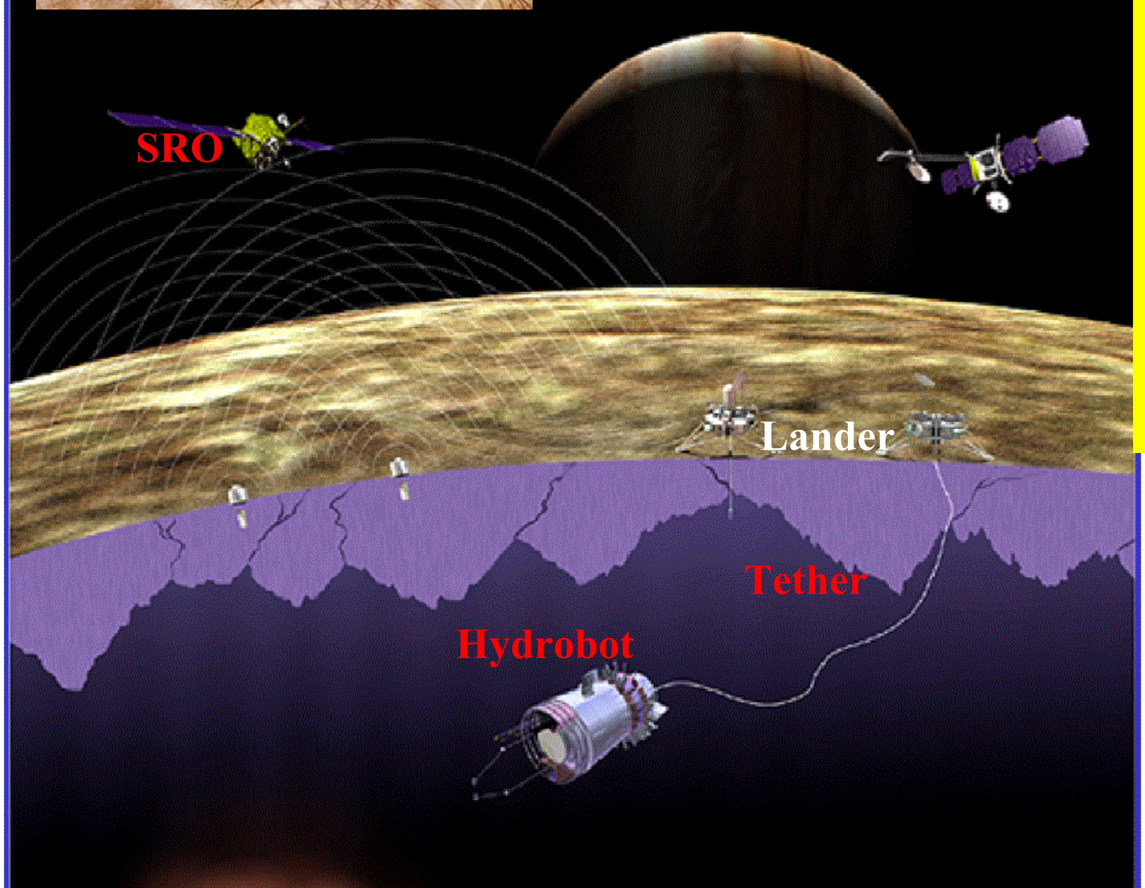
•Begin with technology data, capabilities, & descriptions available in NASA Inventories & data Resources; Consult DoD and Industry archives and Technology programs

•Consult with NASA , & Space domain technology experts to categorize the fidelity of the cost & confidence in meeting performance requirements, and to define a risk and performance metric/figure of merit for each Europa Lander technology element .

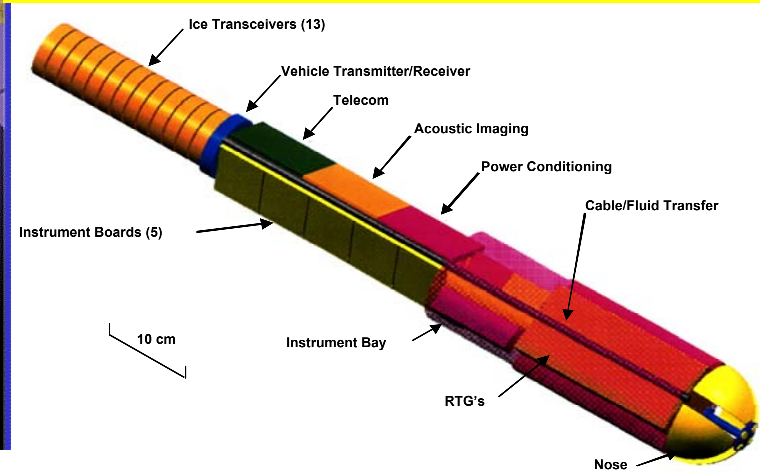
EL - LIFE DETECTION



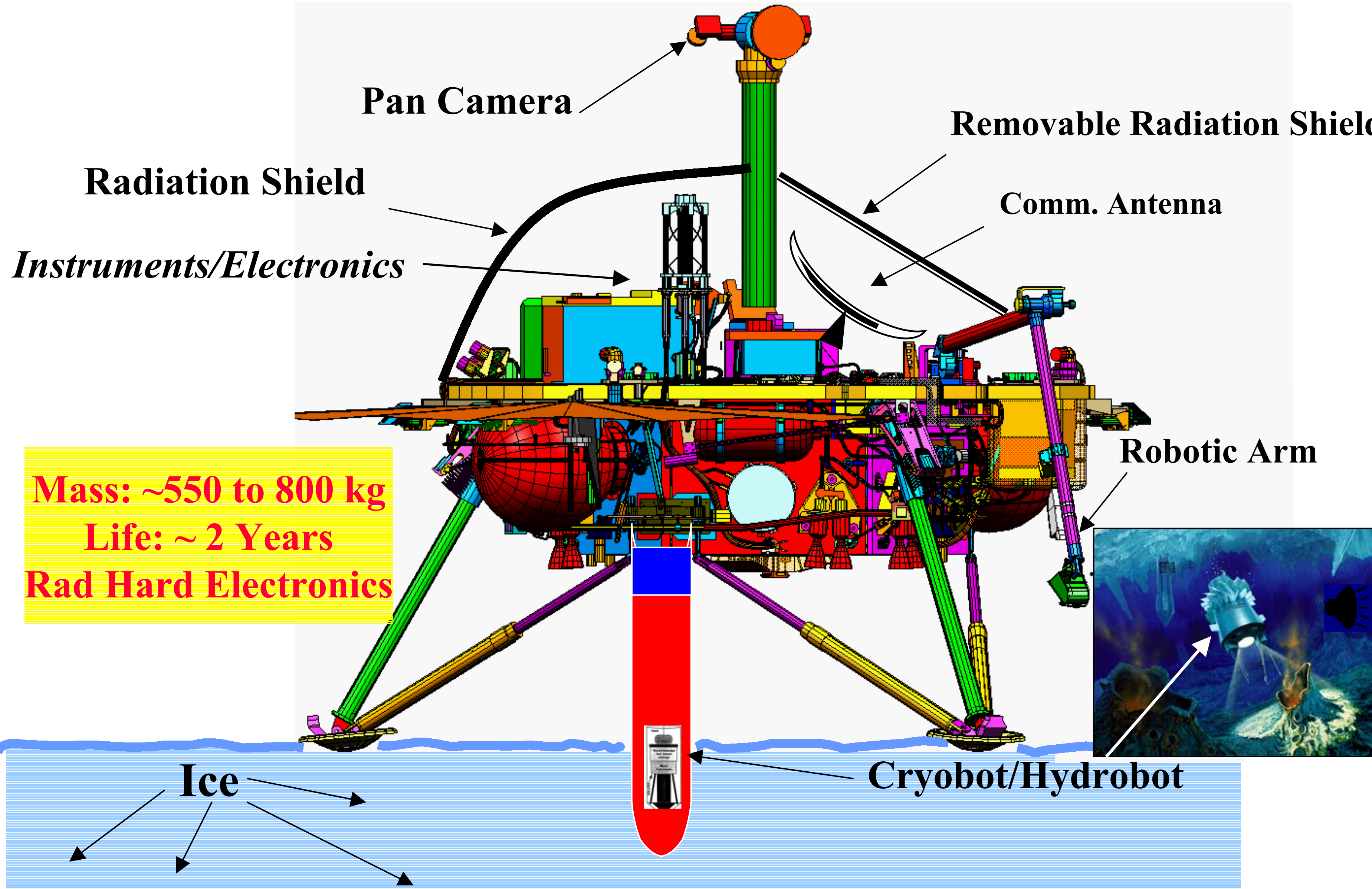
Surface / Subsurface Research and Operations Concepts



By
Chuck Weisbin
Ram Manvi *(Presenter)*
&
Wayne Zimmerman
JPL
10/02/2001



Europa Lander Concept



Europa Lander technologies for R&D

CAPABILITY	PERFORMANCE METRIC (Now/Required)	TECHNICAL CHALLENGES & *BREAKTHROUGH TECHNOLOGIES*
1. Europa Surface Penetration	0.005 (km)/ 3 to 4 (km)	Autonomous Operation in very Low-Temperature hard Ice & Ice/ Non-Ice Composite Material: *Motion, Intelligence, Navigation, Control, Sample Acquisition, Acoustic Image Interpretation of Complex Media, Communication*
2. Extended Survivability	0.04 (Yr.)/ 2 (Years)	Exposure to Intense Radiation (Several Mrads), Very Low-Temperature, and possibly Corrosive media, Very High Ambient Pressures: *Radiation Hardness, Adaptive Skin /Surface Treatment, Intelligent Thermal Control, AI for Dynamic Ice Environment, Liquid Filled Glass Ports (for the Submersible) to withstand pressure(~ kbars).*
3. Life Detection	200 (kg)/ 5 (kg)	Structure, Mass Distribution, and Morphology of Organics, Chirality of Molecules: *Automated Sample Handling/Routing, GCMS with multi columns, HPLC, on-board ESEM, & Raman Spectroscopy*
4. Autonomous Hardware	0.35 (#)/4.26(# DigOps /W-cm^2)	Control, Robustness, Redundant AI Protocols: *In-situ processing of Science Data & Reduction, AI for Data Storage, Feature Recognition, Robotic Sample Acquisition, Site Selection,*
5. Communication	10 (kbs)/100 (kbs)	High Data Rate & High Volume Communication through Ice/Non-Ice Composites, and Water. *Data Storage ~150 Mb, High Compression,Wide-cone Tranceivers , Autonomous.*

Europa Lander technologies for R&D

CAPABILITY	PERFORMANCE METRIC (Now/Required)	TECHNICAL CHALLENGES & *BREAKTHROUGH TECHNOLOGIES*
6. Propulsion and Transit	~10-100 Kg/KW/ ~4.4 Kg/KW	10-20 mt mass delivery to Jovian System ; ~ 3mt delivery to Europa Orbit; ~C3 of 90 for Europa (versus 16-25 for Mars); Mapper/Lander delivery to Europa after 1-2 months; Major Radiation Exposure : *Nuclear Propulsion technologies, low/high thrust technologies for use with planetary exploration*
7. Autonomous Hazard Detection and Avoidance	50 km X 300 km (Mars) ~10 km (Moon) / .5 km (Europa)	Automatic re-direction of Lander during descent and adherence to landing within .5 km of targeted site: *Terrain imaging and processing, autonomous redesignation*

“E^3 - Europa Lander” Summary

Summary

This study only focused on one concept of many, bearing technology indications that could change due to timelines and objectives. The E^3 - Europa Lander concept recognizes technologies that apply to more than one enterprise, one mission or one focus.

Future RASC involvement

Advance the study into a whole program of outer planet explorations, and complete analyses and concept trades to further define technologies that benefit multiple areas in an accelerated timeframe.

Backup Slides

RASC Approach

Identify Breakthrough Technology(s)

- How does it enable Europa exploration? Other missions?
- Alternative capabilities

Alternative Technical Approach

- How do they compare?
- Current state of readiness for the Europa Lander Mission? Now apply RASC effort towards technology usage

Performance Projections

- Quantitative metrics to describe the current state of art and practice?
- Projected future capabilities
- Additional R&D costs?
- Performance pay-offs?

Development/Validation Strategy

- What technical work needs to be completed for the technology to advanced and be ready for use?
- Risks

Technology Roadmap

- Funding priorities necessary to bring the selected technology to readiness 6 or higher?
- What technology options can be available for mission use in 2025 and beyond time frames ?

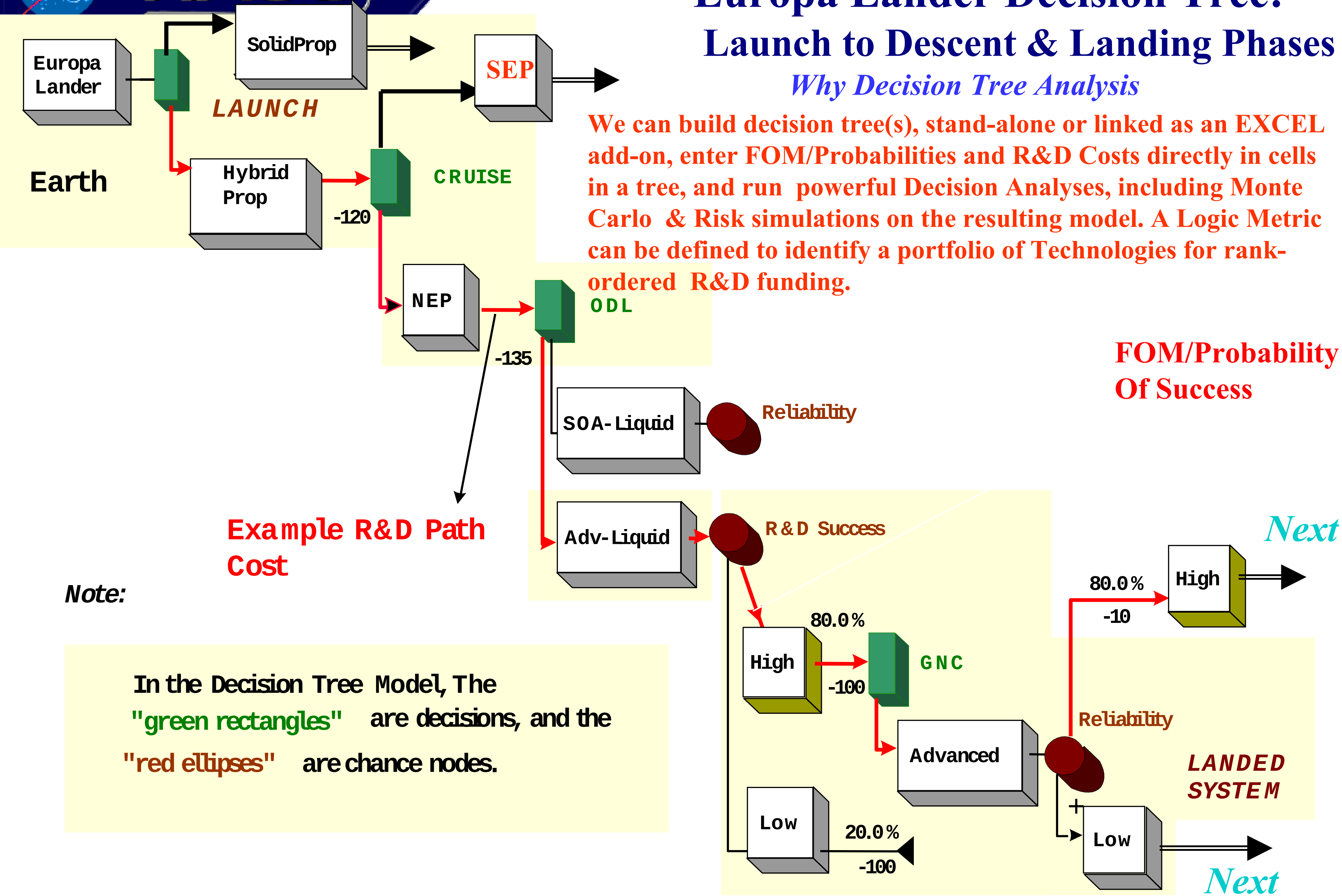
Budget Profiles

- Estimate resource requirements for development and validation? To achieve a specific probability of success for a given technology?

Europa Lander Decision Tree:
Launch to Descent & Landing Phases

Why Decision Tree Analysis

We can build decision tree(s), stand-alone or linked as an EXCEL add-on, enter FOM/Probabilities and R&D Costs directly in cells in a tree, and run powerful Decision Analyses, including Monte Carlo & Risk simulations on the resulting model. A Logic Metric can be defined to identify a portfolio of Technologies for rank-ordered R&D funding.



Note:

In the Decision Tree Model, The "green rectangles" are decisions, and the "red ellipses" are chance nodes.

Figure of Merit (FOM)

- M_S=Performance metric at start of past R&D
- M_A=Performance metric that is achievable by continued present funding rate until Mission Need Date
- M_R=Performance metric required by the Mission
- M_N=Performance metric now, at the present time.
- DD: Degree of Difficulty on a scale of 1 to 9
- TRL: Technology Readiness Level on a scale of 1 to 9

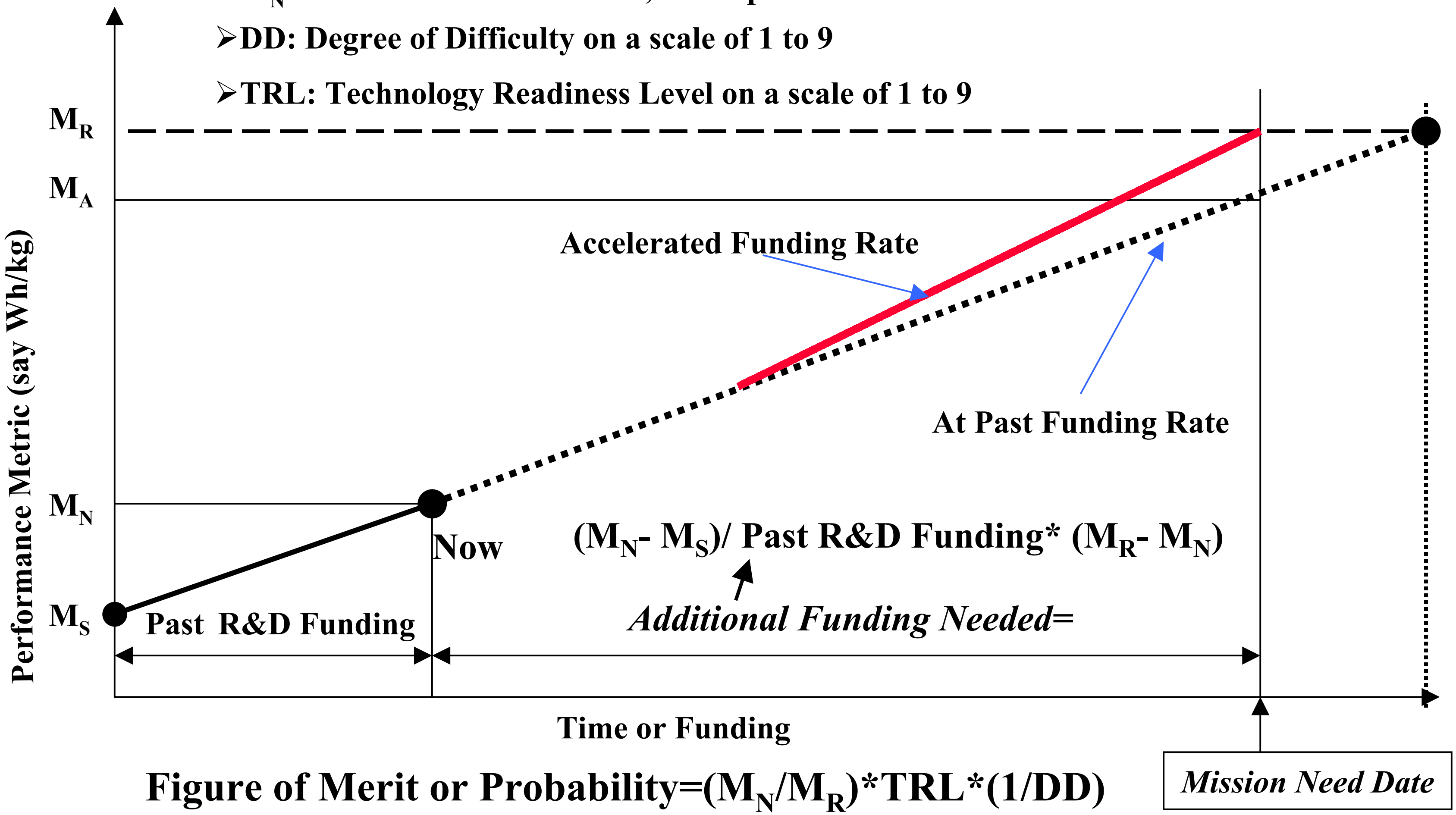


Figure of Merit or Probability=(M_N/M_R)*TRL*(1/DD)

EL Technologies: Preliminary identification for R&D Funding

Baseline Values

	Technology	R&D (M$) Cost	Performance Pnow	Preq	Initial FOM	Final FOM	dP/dC	Logic Metric (X10^3)
1	*Deep Ice Penetration (km)*	35	0.005	4	0.001	1.0	0.0285	22828.57
2	*Extended Survivability (years)*	20	0.04	2	0.020	1.0	0.0490	2450.00
3	*Excellent Life Detection (kg)*	40	200	5	0.025	1.0	0.0244	975.00
4	*Autonomous Hardware; (#dig ops/W-square*	15	0.35	4.26	0.082	1.0	0.0612	744.76
5	*High Volume COMM (kbs)*	14	10	100	0.100	1.0	0.0643	642.86
6	*Thermal Control System Hardware (kg)*	15	7	3	0.429	1.0	0.0381	88.89
7	*High Data Rate COMM; (BPS/W-gram)*	12	90	180	0.500	1.0	0.0417	83.33

Sensitivities to Cost (1.25), Pnow (1.5); and Preq (0.75)

	Technology	R&D (M$) Cost New	Pnow New	Preq New	FOM New	FOM Final	dP/dC	LMetric (X10^3)
1	Deep Ice Penetration (km)	43.75	0.0075	3	0.003	1.0	0.0228	9120.00
2	Excellent Life Detection (kg)	50	300	3.75	0.013	1.0	0.0198	1580.00
3	Extended Survivability (years)	25	0.06	1.5	0.040	1.0	0.0384	960.00
4	Autonomous Hardware; (#dig ops/W-square cm)	18.75	0.525	3.195	0.164	1.0	0.0446	271.24
5	High Volume COMM (kbs)	17.5	15	75	0.200	1.0	0.0457	228.57
6	Thermal Control System Hardware (kg)	18.75	10.5	2.25	0.214	1.0	0.0419	195.56

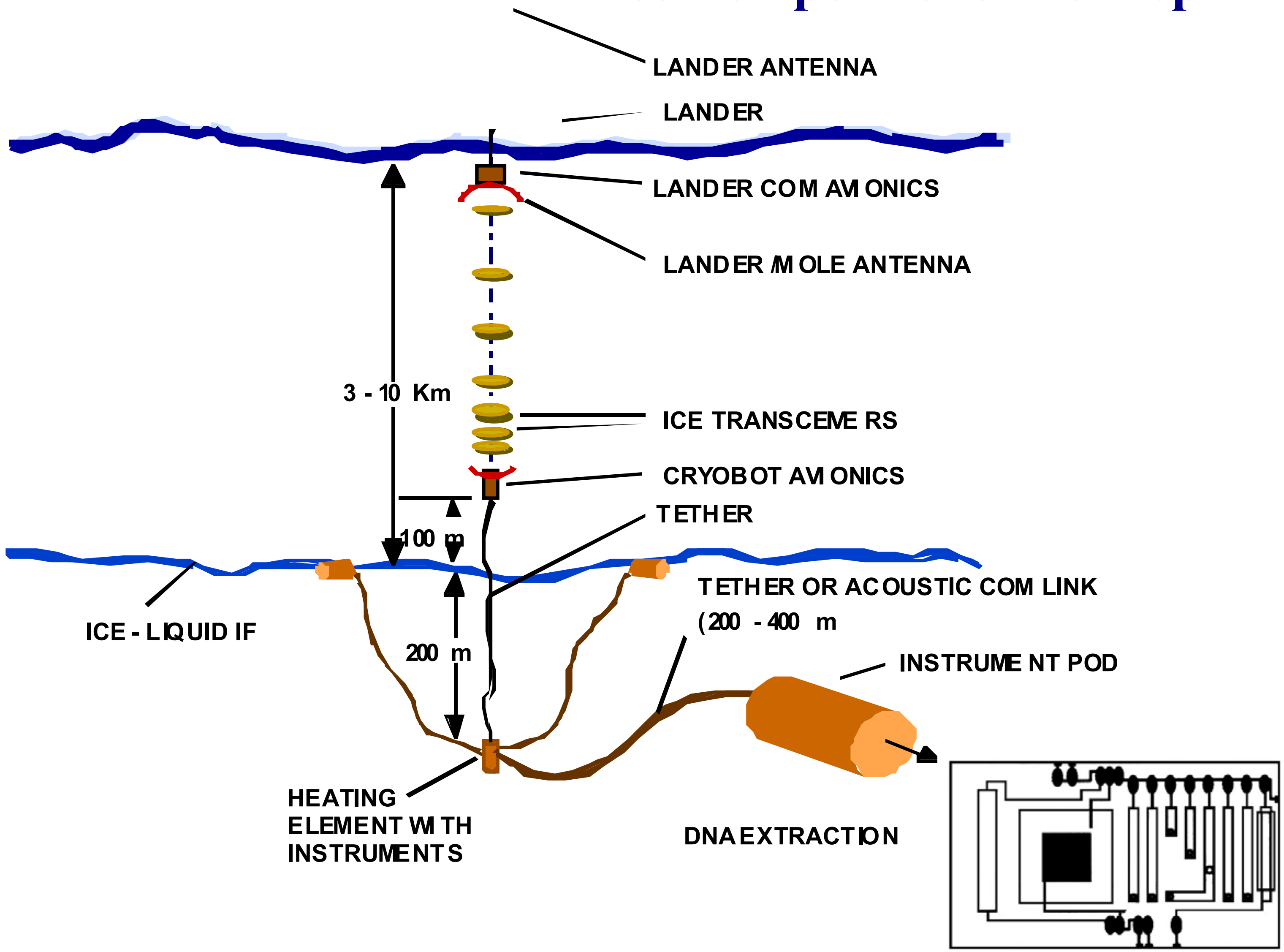
Europa Mission Propulsion and Transit

- Mission strategy was chosen to minimize mass and time in Jupiter's radiation environment--Key technologies targeted are nuclear electric propulsion (NEP) and radiation hardening
- In-space propulsion system technology justification:
  - Projected low-thrust propulsion technologies yield mass fractions 2 to 20 times better than projected high-thrust systems
  - Distance from Sun precludes use of solar power; nuclear chosen as best option to maximize synergy of vehicle systems
- NEP technology:
  - Performance metric: NSTAR specific mass = 18.11 kg/kW, target for Europa mission = 4.4 kg/kW (1-10 kW system)
  - This technology is KEY for this mission, but since cost data is uncertain, NEP was not ranked as one of the top 5 technologies (see later chart)
  - Possible development cost sharing with other outer planets missions
- Current mission concept requires a lift capability of 10-20 mt to nuclear-safe Earth departure orbit
  - Payload includes Relay Orbiter (600-800 kg), Mapper/Lander (1100-1300 kg), and In-space propulsion system for delivery to Jupiter, then Europa
  - Nuclear-safe launch concepts were not addressed specifically but could require in-space assembly and/or autonomous rendezvous.

Europa Mission Descent and Landing

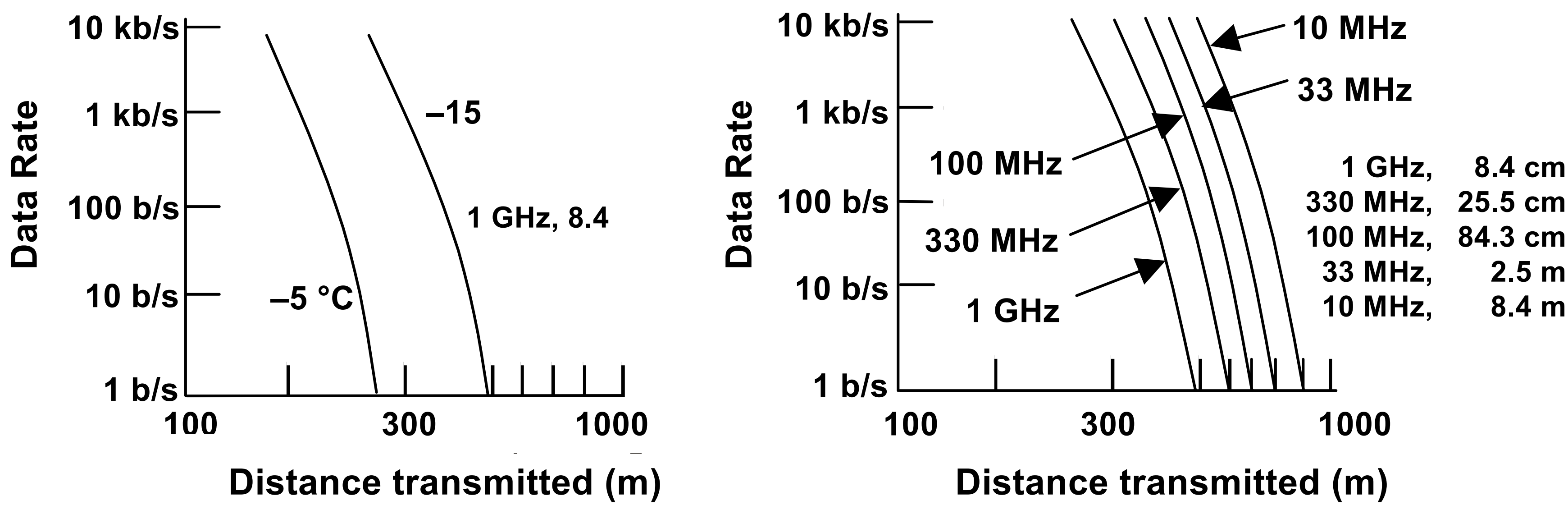
- Landing is accomplished with simple orbital transfer from the mapping orbit established with transfer propulsion system (Lunar-like, powered landing using chemical propulsion)
- Mapper/Lander descends to Europa for surface science phase
  - Communications are provided during descent, landing, and surface operations
  - Mapping phase enhances navigation (state and surface knowledge) accuracy, producing small landing errors
  - Lander fuel for 100 m of local terrain avoidance has been included in mass estimates
- Key technology targeted is hazard detection and avoidance (terrain imaging and processing, autonomous redesignation)

Optimal Relay Drop-off Intervals as a Function of Ice Temperature and Depth.



Comm - RF Signal Attenuation in Ice

RF Signal Attenuation in Ice as a Function of
• Ice Temperature, and Assumed Impurities (Salt Water).



Planetary Exploration - Communications